Using Daylighting in Highly Luminous Climates: Visual Comfort and Performance

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ABSTRACT: Countries having climates of high solar radiation can benefit from favourable natural lighting conditions to achieve energy savings and visual comfort in office spaces. However, potential problems may arise from excessive contrast between the area close to the window and that opposite to it. Uncontrolled access of solar radiation increases thermal loads during summer, affecting air-conditioning systems. Integral glazing/shading systems are rarely considered although they improve overall energy performance and provide visually comfortable uniformity. This work presents a qualitative and quantitative approach to evaluate daylighting systems for such climates.
Three systems for a sidelit office space were analysed in an environment of high solar radiation: a single window without external protection, a horizontal lightshelf and a basic anidolic concentrator mounted on the view window. Radiance simulations for different seasons during the year and hours of the day were made on a prototype corresponding to a deep office space typology that includes enhanced reflectance in the surfaces' finishes. The systems are compared for illuminance and glare performance. Recommendations and architectural implications are presented and discussed.

Keywords: daylighting, office buildings, glare, high solar radiation

1. INTRODUCTION

It might be thought that illuminance requirements for office tasks can be met easily in countries with high solar radiation, for the whole year and during most regular working hours. The potential exists for substantial energy savings through fewer use of artificial lighting.

Even though, a conflict occurs from uncontrolled admittance of natural light. It can bring undesirable high visual contrast between perimeter areas and those located at the depth of the room. Cooling loads increase due to the additional incoming radiation as well.

Due to the reasons stated above, most local efforts to achieve climate-conscious architecture concentrate in keeping openings with reduced size, or at the same time providing them with shade control elements. However, light re-distribution elements are rarely considered in addition to being less known.

This paper compares by means of computer simulations, visual comfort and performance of three available systems. They comprise a single unprotected double glazed window, a lightshelf and a basic anidolic concentrator.

These devices help to improve the quality of office spaces by redirecting and redistributing daylight under a climate of high solar radiation. It is a selection from a wider study [1] that combines both qualitative and quantitative factors and includes more systems, times of the year and orientations.

Usage recommendations are given on how this procedure can become part of an architectural design strategy based on the evaluations mentioned above.

2. DESCRIPTION OF THE SYSTEMS AND EVALUATION ENVIRONMENT

2.1 Prototype Setup

The systems were modelled using Desktop Radiance and functioned as the sole external wall of an office space with dimensions 800 (width) x 1200 (depth) x 270 (height) cm, with the reference workplane at 80 cm. This prototype corresponds to a deep office space typology, chosen to test the maximum reach of each system. Vertical height is assumed to be the third floor of an office building, placed around 10m over the ground which has a reflectance of 0.20.

The materials of the walls, ceiling and floor of this model take into account visual comfort and improved optical qualities with the following values [2] for reflectance = walls 0.65, carpet 0.20, and acoustic slab ceiling 0.80.

The geographical location is Tel Aviv, Israel (32N 35E, standard meridian 30E) due to its high concentration of office buildings, and the possibility of large energy savings through adequate distribution of available natural light [3].

2.2 Sizing and selection of the systems

The basecase system consists of a single view window made of clear double glazing and height 170 cm as shown in Fig. 1(a). It extends for the whole width of the prototype room and has a windowsill of 100cms.

The second system has the same characteristics as the basecase, except it is a lightshelf of highly reflective material (r = 0.80) which has been added according to the dimensions of Fig. 1(b), leaving a clerestory section of 50 cm.

The third system is a basic parabolic anidolic concentrator [4] mounted on the upper part of the view window as shown in Fig. 1(c), with an exit glazing of 70 cm.

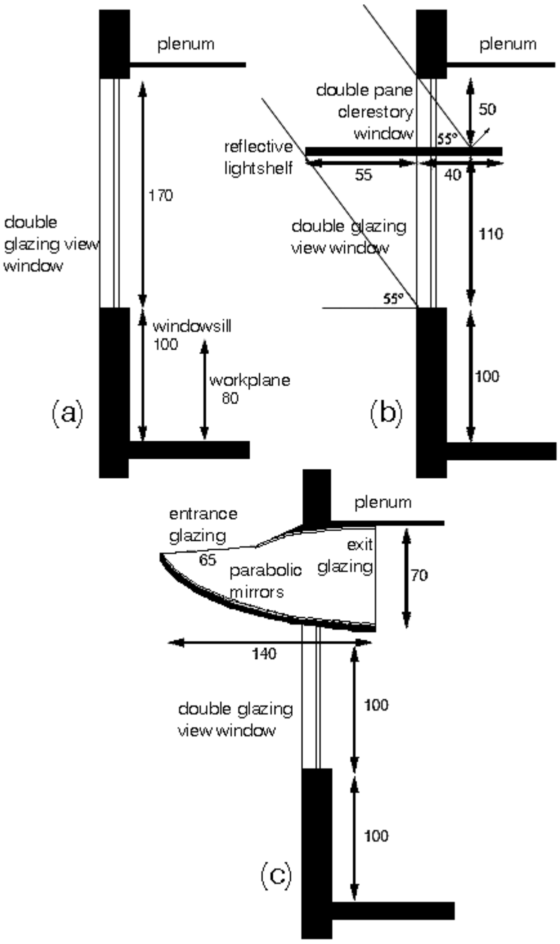

Figure 1: Systems used for evaluation: (a) basic view window (b) reflective lightshelf (c) parabolic anidolic concentrator. Dimensions in centimetres.

The solar angle of incidence for noon, 21 March (55 degrees) was used to determine the geometry of the daylighting systems, as detailed in Fig. 1(b). This angle of incidence was considered an intermediate position that accounts for shading during both summer and winter.

Their visual properties and sizing are intended to reflect light into the depth of the room and decrease light levels at the front, in order to balance light distribution and improve visual comfort.

These systems also contribute to save energy consumption through reduced admittance of solar radiation. This is demonstrated in Fig. 2 which has been adapted from a separate study [5] for the same location, and that focused on the energy consumption effect of external lightshelves as horizontal shading devices.

The graph corresponds to a South-facing office with depth 6.7 meters, where applying a lightshelf of 50 and 100 cm decreases energy loads per square meter per year in terms of cooling and electric lighting.

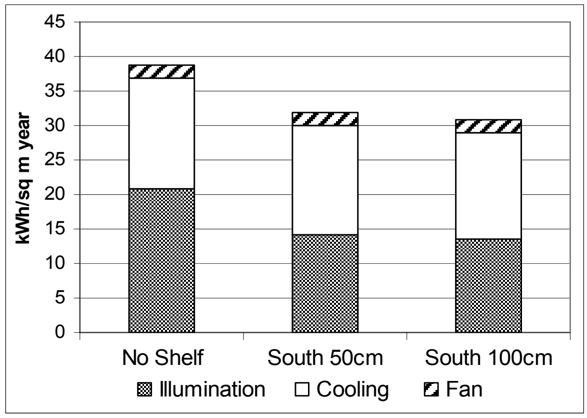

Figure 2: Influence of external lightshelf length in reducing illumination and cooling loads in a South-facing office, Tel Aviv. After Shaviv et al. [5]

2.3 Simulation Dates and Mimic of User Behaviour

In this paper we present results for 21 June and 21 December for the South orientation, even though the complete experiment includes 21 March and September and all four compass directions. Testing hours for each of these dates are 10, 12, 14 and 16 h. The CIE intermediate sky with sun was applied, since it was determined to be suitable for the local conditions [1].

The aim of the study is to integrate qualitative and quantitative evaluations, since presenting illuminance data only can be misleading. Users will react to provide themselves with visual comfort if they are faced with unfavourable situations, as it occurs in completely glazed offices lacking curtains [6]. Therefore, a movable shading device such as a venetian blind was also included in the study.

Computer simulations of human response to natural light through shading devices like internal blinds need careful understanding for adequate modelling [7]. Here it is simplified as follows: blinds are assumed to be lowered completely in the open, horizontal position when the Radiance simulation picture shows direct solar penetration (sunspot) over the office's floor beyond 1m from the view window. These blinds do not cover the clerestory part of the elements.

2.4 Glare Analysis

Even though it is a complex qualitative issue that needs further research and understanding, glare from large natural sources can be numerically quantified through scales such as the daylight glare index (DGI) [8] which is used in this study.

Radiance assigns luminance values to the pixels composing the pictures it generates, making feasible the evaluation of glare indexes through image analysis with such information. This method has been used by Schiler [9] to detect post-occupancy glare conditions by statistically analyzing pixel luminance information from digital cameras and is gaining acceptance as a research method [10].

The view point in this study is 100 cm from the window and faces it directly. This represents the worst case view point, even though it is a limiting condition imposed from glare formulas that are presently accepted [11]. Other view points were considered but as is detailed in Section 3.2, results proved inconclusive.

3. RESULTS AND ANALYSIS

3.1 Illuminance Evaluations

Hundreds of parametric simulations were done comprising all four orientations, but the most relevant data for the South-facing prototype is presented in this paper. Quantitative results are summarized in Figs. 3, 4 and 5. They are used to characterize how the devices perform during different seasons and also hour by hour on representative dates.

Fig. 3 is a histogram comparing the illuminance performance for all three systems year round at different depths of the room (200, 600 and 1200 cm). The basecase is detailed without blinds at all times and blinds operating as described in the previous section. To gauge their operation, absolute illuminance limits were set in the histogram [12]. The minimum was set at 300 lx, and the maximum at 4,000 lx.

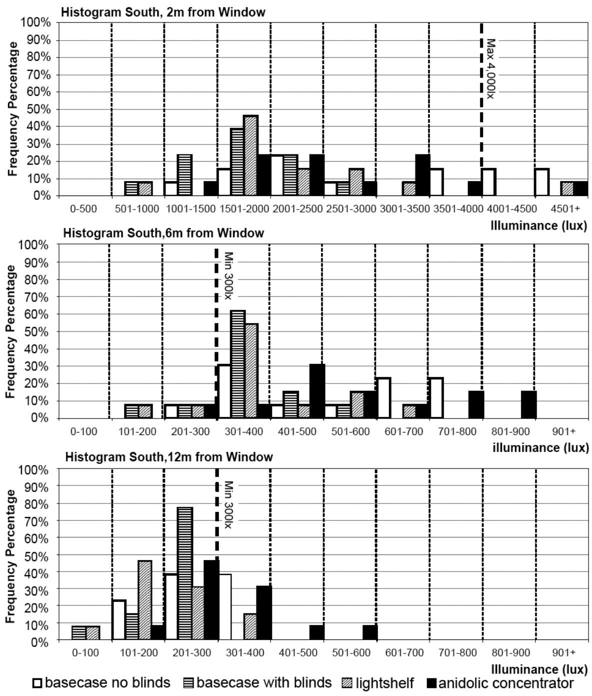

Figure 3: Histogram of year round illuminance performance for three sidelit daylight systems at 2, 6 and 12m in a South-oriented prototype, Tel Aviv.

From the histogram it can be seen that the effectiveness of the systems decreases after 6 metres, except for the anidolic concentrator. This device could keep more frequently lighting levels slightly above the minimum of 300lx even at 1200 cm from the window.

Fig. 4 shows illuminance distribution line graphs for 21 December, while Fig. 5 for 21 June. In both cases results are detailed for 10, 12 and 16 hours. These graphs also correspond to the South, with the view window at the left hand side of them.

Operation with blinds off at all times is represented by a continuous line while its use is represented by a dashed line.

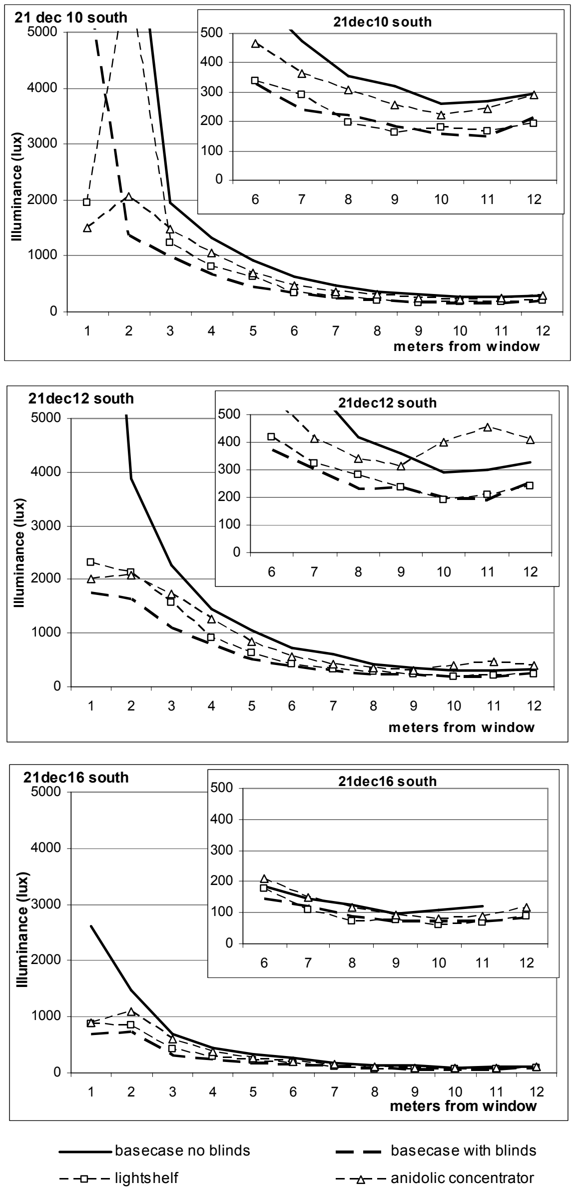

Figure 4: Illuminance graphs for three sidelit daylight systems facing South on 21 Dec at 10, 12 and 16 hrs, Tel Aviv. Window on left-hand side.

These graphs demonstrate how visual comfort improves by means of well-designed daylighting redirection elements. Calculating their size to shade the area close to the window reduces absolute lighting levels close to it (where they are quite strong).

The anidolic concentrator, planned to reflect incoming direct natural light, helped to increase lighting levels at the end of the room, while the lightshelf helped to reduce absolute differences between front and bottom. This hour by hour analysis also confirms that device efficacy is reduced after a distance of around six to seven meters.

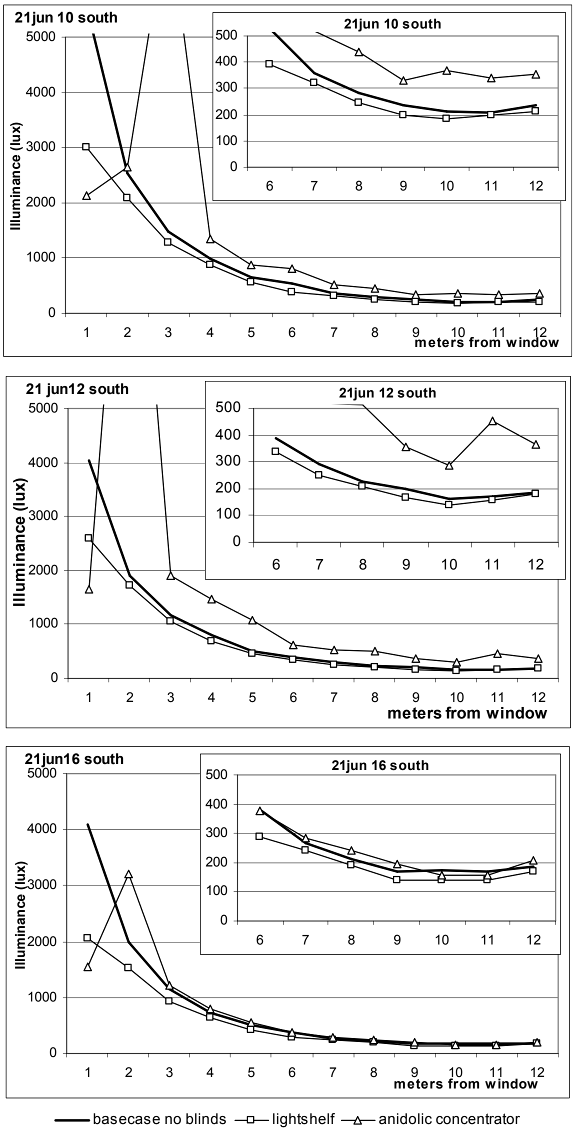

Figure 5: Illuminance graphs for three sidelit daylight systems facing South on 21 June at 10, 12 and 16 hrs, Tel Aviv. Window on left-hand side.

3.2 Glare Evaluations

As mentioned before, qualitative issues are compared through the DGI glare index. The limit for "just acceptable" glare was set on 22 [13]. Since mainstream glare evaluation formulas impose the observer looking directly to the window, this was taken as the worst case scenario. Additional positions such as looking to the walls were considered.

Visual comfort evaluations for all these positions were made considering the same period as illuminance simulations, but results proved inconclusive for many of them, including the frontal viewpoint. For the side viewpoints, results could not be compared since the glare source could occur behind the observer's view point or be directly on the edge of the simulated visual field.

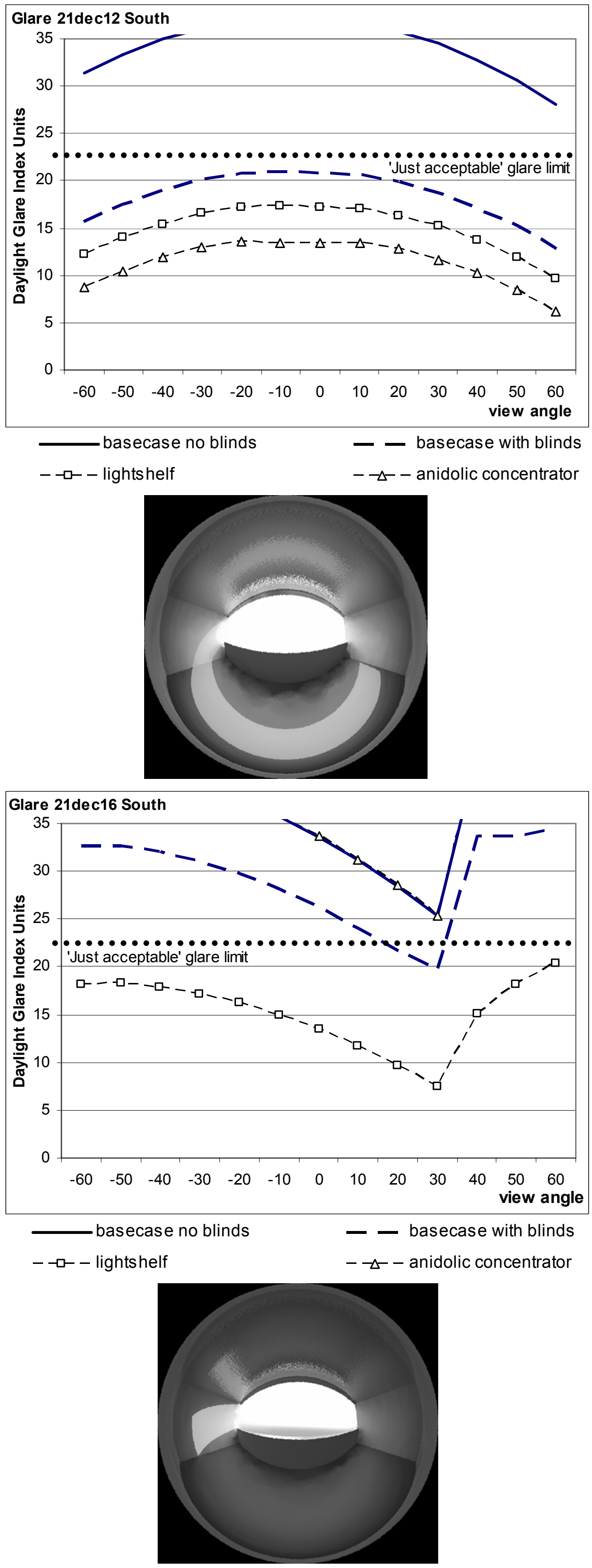

Figure 6: DGI graphs for three sidelit daylight systems facing South on 21 Dec at 12 and 16 hrs, Tel Aviv and matching Radiance pictures for basecase without blinds. Just acceptable glare limit below straight dotted line.

Fig. 6 illustrates two representative glare evaluations with clear results. It shows daylight glare index graphs for the systems oriented to the South, on 21 December at 12 and 16 hrs. Areas below the straight dotted line indicate the “up to just acceptable” glare limit. Additionally, corresponding Radiance-generated pictures for the basecase without blinds are presented to explain the trends.

It can be seen that blinds contribute to the reduction of glare, but are not enough protection by themselves for all times. Devices projecting out of the window such as the lightshelf, contribute in reducing contrast glare.

Elements that depend on the reflection of direct natural light such as the anidolic concentrator do not produce glare when the sun shines at a high angle. This corresponds to the situation for which they were optimized.

However, as seen from both Figs. 4 and 6, when the solar angle is lower the concentrator achieves its highest illuminance levels; but also has the risk of becoming a source of glare on these occasions.

Although lightshelves might not give the same absolute illuminance levels as the anidolic concentrator, they are less likely to become glare sources when users look directly to the window. This is due to their functioning based on diffused daylight, and that the shiny surface never “looks” to vertical surfaces inside the room.

4. ARCHITECTURAL IMPLICATIONS AND RECOMMENDATIONS

Previous sections have demonstrated that analyses including quantitative and qualitative aspects are necessary to formulate architectural design strategies focused on improving natural light conditions of workplaces located in climates with high solar radiation.

For such, it is proposed to use the method described in this study. This includes examining both illuminance and glare for each orientation and time of the year that is needed.

The following are some architectural propositions towards effective performance of daylighting systems in climates with high solar radiation, while keeping visual comfort. As a design strategy, they can help to enrich the vocabulary available in hot climates towards efficient use of natural lighting in office spaces while optimizing energy usage.

4.1 Architectural Implications

The research proved that use of daylighting devices is feasible for office buildings in hot climates. This can provide “away from the box” alternatives to designers wanting to give a distinguished image to their project, one that reveals a smarter use of natural resources.

Other, and perhaps more fundamental changes derived from using daylight systems, come when planning usable depth in office buildings. The distance is tied to the maximum reach of the devices. Such considerations impact on the intended massing of a project.

Window sizing can be increased in the measure that devices doubling as shading protection are used. Increased heights of the working space have to be taken into consideration.

Since the best results from the systems are achieved when placed in an environment of materials with high reflectance, care must be taken when specifying them. Many manufacturers are incorporating to their catalogs elements with improved visual properties, therefore increasing their market availability.

The option also exists to put into operation these devices in either the design of new buildings or the renovation of many existing ones.

But the most promising implication is where a work environment that manages daylight adequately gives, as proved through many studies, a positive incentive on productivity and well being of employees.

4.2 Architectural Design Suggestions

Some architectural recommendations applied to the design of office spaces implementing these devices are the following:

- Floor plans should be sidelit up to a distance of 6-7 meters. This ensures that both reach and efficiency of the devices are optimal. When further depth is needed, a second opening or an atrium must be considered.
- Preferable floor to ceiling height must be no less than 3m to allow better daylight penetration and redirection [14], [15].
- Window size can be enlarged compared to traditional buildings, but is dependant on shading properties of the daylight redirecting device.
- When dealing with renovations, it is important to take them into account for structural purposes.
- Sizing and geometry of each device must be the result of a careful study that also considers local conditions, such as surrounding buildings.
- Maintenance must be taken into account both in the design and occupancy phase. In the first phase, access must be provided for cleaning (including demounting); while in the second, a program must be implemented to keep efficient finishes throughout the life of the project.
- If possible, provide a design furniture layout that helps to avoid glare (for example, one where users seat with computer screens perpendicular to windows and not parallel to them).
- Instruct users to know the reasons and working behind daylighting devices that were installed in their workplace.

4.3 Recommended Usage According to Orientation

A ranking is given on Fig. 7 on how suitable it is to use each of the systems presented in this paper for a required direction.

The suggested use, as shown in the figure, is based on the wider study for the location, and includes the basecase with and without blinds as a reference.

The values are stated in three steps from appropriate to inappropriate. The term partially appropriate is used to describe a device that requires further modifications from its initial configuration or careful design in order to avoid glare and provide adequate visual comfort.

Device	North	South	East	West
Basecase no blinds	✓	✗	✗	✗
Basecase with blinds	✋	✋	✋	✋
Lightshelf	✗	✓	✋	✋
Anidolic	✋	✋	✋	✋

Symbol	Meaning
✓	device is appropiate for the orientation
✗	device is inappropiate for the orientation
✋	device is partially appropiate for the orientation

Figure 7: Usage recommendations of sidelit daylighting systems according to orientation, Tel Aviv.

Nevertheless, it must be pointed out that these results are valid for systems having a basic geometry configuration. Only natural light was used in the prototype; human interaction strategy was limited to the use of blinds in one position.

It must also be remembered that the prototype did not consider obstruction patterns, since they are highly variable and a precise study of local conditions is necessary in order to define them.

5. CONCLUSION

Combining visual comfort and performance evaluations served as a tool to examine the suitability of daylighting systems under high solar radiation. The method proved useful to determine design strategies for their use. The main points of these strategies were stated for their application.

Further research points that can refine the evaluation tool are related to improvement of glare evaluations, interaction of the systems with artificial light and optimization of device geometry.

The evaluation tool used in this study increases its importance when considering dynamic or intelligent daylighting devices, for example mobile sun tracking concentrators or motorized blinds.

Through the use of such tools and design strategies it is hoped to use efficiently a widely available resource and turn it from a potential problem into an architectural design aid.

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